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Searching for Z' and model discrimination in Atlas

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If a heavy Z' boson exists, it could be one of the first particles to be discovered at the LHC, since its decay into two leptons will provide a clean signature. Interpreting the resonance may be more complicated. Here, we summarize a full detector simulation study on the possibility of distinguishing between models of Z' like narrow resonances, using as observables the width, cross section and forward-backward asymmetry.

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The presence of additional neutral spin 1 bosons (denoted as Z' in this note) is predicted in many extensions of the Standard Model: models derived from the breakings of the E_6 gauge group, left-right symmetric models, extra dimensions models... The current most stringent limits are derived from the recent searches at the Tevatron[1][2] and range between 600 GeV and 800 GeV, depending on the assumed model. The Large Hadron Collider at Cern whose first collisions are expected in fall 2007, should open a new frontier in this field : bosons of mass up to 4 TeV could in fact be discovered in one year of data taking at the design luminosity (see [3] for instance).

If a Z' is discovered, the next challenge will consist in determining the underlying theory at the origin of this new gauge boson; this can be done by precisely measuring specific observables such as : natural decay width, rapidity, forward backward asymmetry... The measurement of the latter, not trivial at a hadronic collider, is detailed in this note, in the case of a Z' decay to electron-positron.

1. Angular considerations

Due to the spin 1 nature of the Z' , its production cross section strongly depends on $\cos\theta^*$, the angle between the final lepton and the initial quark in the rest frame, with the behaviour:

$$\frac{d\sigma}{d\cos\theta^*} \propto \frac{3}{8}(1 + \cos^2\theta^*) + A_{FB}\cos\theta^* \quad (1.1)$$

Checking this dependence can be a way to probe the spin value of the new gauge boson but also to disentangle between spin 1 models by precisely measuring the A_{FB} parameter. This measurement is challenging at the LHC, where the direction of the initial quark remains inaccessible.

In all the following, two angular quantities are considered:

- $\cos\theta^*$ is the angle between the outgoing electron and the quark, in the Z' rest frame, deduced from the generator history.
- $\cos\theta^\otimes$ is the angle between the outgoing electron candidate, in the reconstructed Z' rest frame, and the direction of the reconstructed Z' .

The first quantity will be used to extract the reference asymmetry, whereas the second one will be used as an estimator; the correlation between the two quantities is represented on Fig. 1(a), two main populations of events being exhibited:

- when the quark is in the same direction as the Z' , the $\cos\theta^\otimes$ quantity is an unbiased estimator of the $\cos\theta^*$ angle, degraded only by initial state radiation, energy and angular resolution. As the Z' is produced by the annihilation of a quark and a sea antiquark, this configuration is the most frequent.
- if not, the estimator is strongly biased, with $\cos\theta^\otimes \approx -\cos\theta^*$

The relative proportion ε of the second population of events can be estimated as a function of the rapidity and is represented on figure 1(b).

2. The A_{FB} extraction

Given relation 1.1, the A_{FB} parameter can be classically extracted at the generation level by a counting method:

$$A_{FB}^{gen} = \frac{N_+ - N_-}{N_+ + N_-} \quad (2.1)$$

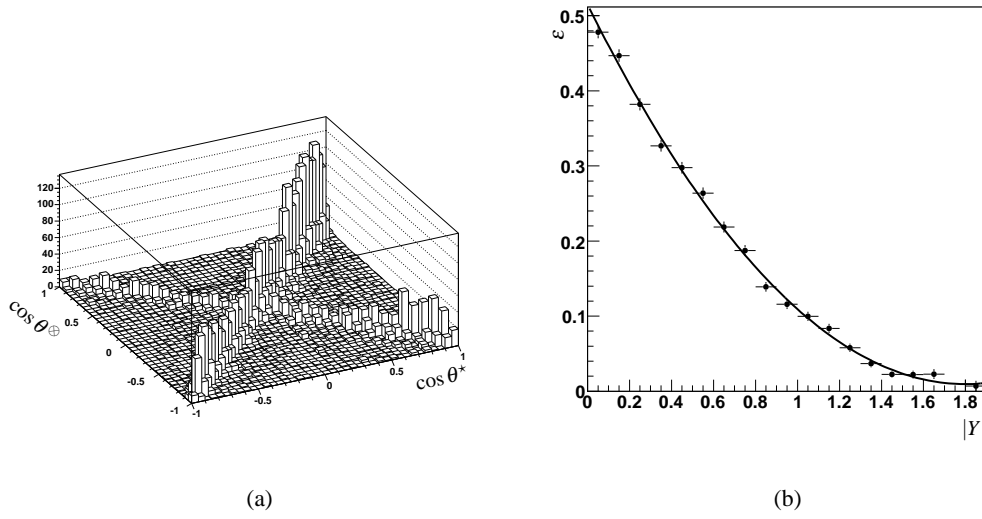


Figure 1: (a) $\cos \theta^*$ vs $\cos \theta^\otimes$; (b) $\epsilon(|Y|)$ at $M = 1.5 \text{ TeV}$ (with a parabolic parametrisation superimposed)

where N_+ (N_-) denotes the number of events with $\cos \theta^* > 0$ (< 0).

Applying the same formula to measure the observed asymmetry by taking $\cos \theta^\otimes$ as an estimator of $\cos \theta^*$ leads to a bias due to the imperfect knowledge of the quark direction. Ignoring the detector effects and the Z' transverse momentum, this bias can be quantified with the knowledge of the ϵ proportion defined in section 1 :

$$A_{FB}^{obs} = (1 - 2 \langle \epsilon \rangle) A_{FB}^{gen} \quad (2.2)$$

A corrected asymmetry is then defined by:

$$A_{FB}^{cor} = \frac{1}{1 - 2 \langle \epsilon \rangle} A_{FB}^{obs} \quad (2.3)$$

This method is very easy to implement and efficient but the whole angular information is unfortunately lost, when integrating over an hemisphere; the spin 1 behaviour of the new particle is consequently not tested at all. To allow such a test, a differential analysis is performed : a differential asymmetry is deduced by a counting method, the quantity N_\pm being extracted on a limited $\cos \theta^*$ (or $\cos \theta^\otimes$) range. The running of this quantity can be easily deduced from expressions (1.1) and (2.1):

$$A_{FB}(\cos \theta) = \frac{8}{3} A_{FB} \times \frac{\cos \theta}{1 + \cos^2 \theta} \quad (2.4)$$

Performing an analytical χ^2 fit to these differential asymmetry distributions in the $[0, 1]$ interval then allows to extract the A_{FB}^{gen} , A_{FB}^{obs} , and A_{FB}^{cor} quantities.

3. Application to the ATLAS case

In order to validate the above method, Monte Carlo event samples have been considered; they have been produced by the PYTHIA generator[4], the ATLAS detector response being simulated in the Geant3 framework. Several models involving a new gauge boson of mass 1.5 TeV have been considered : χ , ψ , η (all derived from a E_6 theory) and a left right symmetric model. Given the ATLAS detector performances,

the signal signature should be very clean (two highly energetic leptons) and the background should remain limited; no background was therefore included in this study.

The three asymmetries detailed in the section 2 are represented on figure 2(a) for the χ model in 5 different dileptons mass bins, and for a luminosity of $100fb^{-1}$. The 5 - independent- measurements exhibit the same behaviour : due to the imperfect knowledge of the incoming quark direction, the observed asymmetry is much lower in absolute value than the one computed at the generation level. Applying the adequate ε correction factor however allows to recover from this effect. Due to the different coupling constants to quarks, a systematic error must be associated to the estimate of the ε quantity; the impact on the A_{FB} measurement was found to be limited, below 10%.

Finally, applying this method on all available samples leads to identical conclusions; on figure 2(b), are represented all the corrected asymmetries; the variety of behaviours is a clear proof of the discrimination potential of this observable.

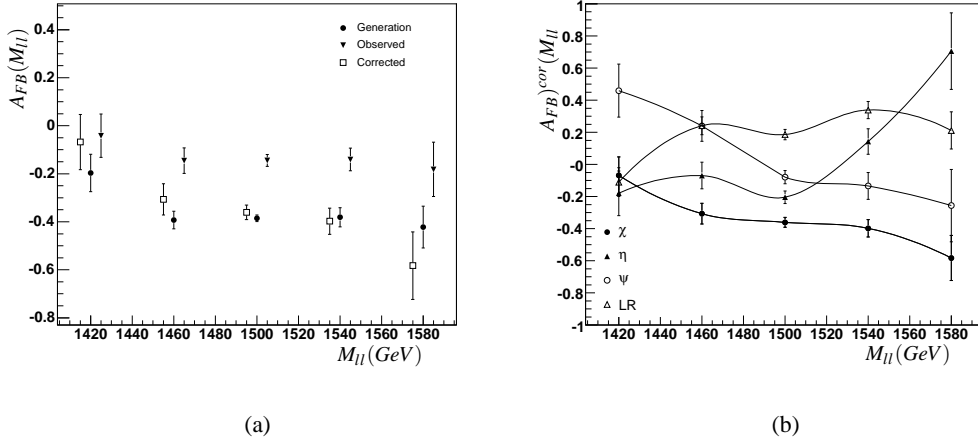


Figure 2: (a) Asymmetries measurement - χ model ($M_Z' = 1.5$ TeV) - $\int \mathcal{L} = 100fb^{-1}$; (b) Corrected asymmetry - $\int \mathcal{L} = 100fb^{-1}$

4. Conclusion

A method to measure the leptonic forward-backward asymmetry at the LHC was presented. The accuracy reached with a realistic luminosity was found to be promising; this measurement, associated with the one of other observables (natural width, rapidity) should provide large constraints on the model at the origin of any -potential- new massive gauge boson.

References

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